MEMORANDUM

Date: May 2, 2023

To: Bill Slater, Slater Environmental

From: Core Geoscience Services Inc.

Subject: Diavik Mine Final Closure and Reclamation Plan - Climate Change Considerations

1. INTRODUCTION

Slater Environmental retained Core Geoscience Services (CoreGeo) to review the Diavik Mine Final Closure and Reclamation Plan submitted to the Wek'èezhìi Land and Water Board (WLWB), with specific focus on climate change considerations, including climate change projections and implications for site water balance, water quality model and major site infrastructure closure design. This memo summarizes findings and recommendations.

2. DOCUMENTS REVIEWED

CoreGeo reviewed the following documents, provided as Appendices to Diavik Mine Final Closure and Reclamation Plan:

- Appendix X-10: Diavik Mine Site - Current and Projected Climate Parameters (Golder, 2021)
- Appendix X-15: Diavik Processed Kimberlite Containment Facility Rockfill Option Closure Design (Golder, 2022)
- Appendix X-16: Diavik Diamond Mine North Country Rock Pile Closure Design (Golder, 2017)
- Appendix X-19: Diavik Closure Site-Wide Water Balance Model (Golder, 2021)
- Appendix X-20: Diavik Diamond Mines Closure Feasibility Study Water Quality Model, 1:100 Dry Year Scenario, and Climate Change Scenarios (Golder, 2022)
- Appendix X-24: Diavik Diamond Mines Climate Change Assessment (Golder, 2021)

CoreGeo referred to guidance documents as needed; those can be found in the reference section of this memo.

3. FINDINGS AND RECOMMENDATIONS

Overall, the climate change assessment used adequate methodology. The assessment follows the methods outlined in *A Guide on Incorporating Climate Change Adaptation into Decision Making for the Mining Sector* (MAC, 2021). Although this document was also prepared by Golder, it relies on an extensive refence list. However, CoreGeo identified concerns regarding the climate change assessment and how projections were used in the closure planning, which are presented below. In addition, CoreGeo identified concerns regarding climate change considerations in cover designs for the North Country Rock Pile and the Processed Kimberlite Containment Facility.

3.1 Climate Projections

Because bias-corrected, and downscaled climate projections were not yet available from the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6, 2021) for the site at the time of writing the climate change assessment, future climate projections from publicly available statistically downscaled daily future climate projections used were based on the Fifth Assessment Report (AR5, 2013).

> *"AR6 uses the latest generation of climate models, coordinated by the World Climate Research Programme's Coupled Model Intercomparison Project, version 6 (CMIP6). […] The CMIP6 climate models are based on updated emissions pathways. In CMIP5 (the previous set of models), Representative Concentration Pathways (RCPs) were used as sample trajectories of radiative forcing which relate to the greenhouse gas effect and trapping of heat in the Earth's atmosphere ultimately resulting in global temperature increases. While useful approximations for understanding a range of climate impacts under different emissions pathways, it was difficult to link RCPs with real-world scenarios for emissions, land use and change and political interventions. As a result, the new climate models use RCPs coupled with Shared Socioeconomic Pathways (SSP-RCPs) which include more robust "storylines" of factors intrinsically linked to climate change, such as population growth, urbanization, and technologic advancements to mitigate climate change. These generally relate to the RCPs used in CMIP5, with RCP8.5 and RCP4.5 still being used (in addition to new RCPs), but now in conjunction with SSPs to provide additional context. SSP-RCPs also more closely align with certain end-of-century temperature targets, such as the 1.5° set forth in the Paris Agreement and provide insight into the timing of crossing certain thresholds. With these new pathways, it becomes easier to understand how different actions could manifest in the form of future climate impacts. In total, five SSP-RCPs will be available for use in climate risk assessment […]. While generally comparable to CMIP5 generation models, CMIP6 has taken a step forward by improving the overall quality of climate projections. […] Projected end-of-century temperature anomalies within SSP-RCPs have a narrower uncertainty range than in AR5, but generally also run slightly hotter compared to previous models."* (Gannon & Boonanich, 2021)

Because AR6 climate projections have not been downscaled for the Project site yet, it is unknown how this will translate locally, but there is potential for predicted climate parameters to be different (potentially hotter temperatures) than under AR5. **Recommendation:** Based on this, it is recommended to run sensitivity analyses to understand the potential implications of a greater temperature increase on the Project Closure Plan. Sensitivity analyses were run for the Processed Kimberlite Containment Facility (PKCF) thermal cover design, but not site-wide. The plan should also include contingency mitigations associated with a greater temperature or precipitation increase.

Diavik's climate change assessment presents climate projections obtained using 24 different Global Climate Models (GCMs) focused on three AR5 Representative Concentrations Pathways (RCPs; RCP 2.6, RCP 4.5, and RCP 8.5). Projections across the multi-model ensemble are summarized in terms of percentiles where the 50th percentile represents the median value and the 95th percentile represents extreme projections for the site. Since the RCP 6.0 pathway is not included (downscaled projections are not available for this pathway), we are concerned that the 50th percentile and to a lesser extent the 95th percentile have a low bias.

Also, Appendix A of the climate change assessment states:

> *"Downscaled outputs are based on GCM projections from the Coupled Model Intercomparison Project Phase 5 (Taylor et al. 2012) and historical daily gridded data across the globe (Sheffield al. 2006) and are available for 21 GCMs. Two scenarios (RCP 2.6 and RCP 4.5) are available for each of the 21 GCMs which results in 42 individual climate scenarios." (Section 2.1.2, p.10).*

It is unclear if the use of the two lower representative concentrations pathways only (RCP 2.6 and RCP 4.5) is also introducing bias in the range of predictions.

Recommendation: Describe any possible bias in climate projections and discuss implications.

Climate projections are available up to 2100, and Diavik's climate change assessment includes a semi-qualitative approach allowing for monthly timeseries of precipitation and temperature variables to be generated up to 2126, along with estimates of the climate projection statistics for the 2120s future period (2106-2135). Certain aspects of the Project closure design are however expected to be maintained in perpetuity (e.g. North Country Rock Pile frozen cover). **Recommendation:** A discussion of the different emissions pathways and of their implications for the Project design in the long-term (beyond 2120s) should be included to better understand if the closure design can be expected to be sustainable over that time horizon.

3.2 Climate Parameters

The current climate parameters were sourced from the baseline climate analysis update (Golder, 2021) in the Current and Projected Climate Parameters compilation document (Appendix X-10). This is different than the current climate parameters used in the climate change assessment which used a longer infilled time series (Appendix X-24). For certain parameters, future climate is presented as % change from current climate, but the "current climate" reference is different in the two documents. This inconsistency could introduce discrepancies and/or inaccuracies and missing data (e.g. some values not available from Golder 2021). **Recommendation:** A reference baseline dataset should be established and used consistently for all models, analyses and projections.

3.3 Water Balance

The water balance model approach evaluates conditions under three closure scenarios (around 2025, without considerations for climate change, around 2125 with consideration for climate change using the 50th percentile projections and around 2125 with consideration for climate change using the 95th percentile projections), but only for an average precipitation year. **Recommendation:** It is recommended that the three closure scenarios also be modeled for a dry (1:100) and for a wet (1:100) year.

3.4 Water Quality Model

The water quality model was run for a 1:100 dry year under current climate and for and average precipitation year under climate change projections (50th and 95th percentile). **Recommendation:** Similar to the water balance, it is recommended that the three scenarios (current climate and two climate change scenarios) be modelled for a dry year (1:100), average year, and wet year (1:100). While a dry year would result in higher contaminant concentrations for a given mass loading, a wet year could result in storm surges and increased flushing of contaminants.

In addition,

> *"The climate change scenarios resulted in lower predicted concentrations, overall. This is due to the cumulative annual mass loading being released over a longer period of time each year (early May through October or November), which results in a smaller amount of mass being released on a daily basis relative to the base case scenario. It is also a function in the increase in the runoff volume. Predicted concentrations decrease with increasing percentile climate change projections." (Appendix X-20, p. 18)*

Recommendation: It would therefore be prudent to also model the lower percentile end of climate change projections (e.g. 5th percentile which predicts a decrease in precipitation).

3.5 North Country Rock Pile Closure Design

Section 4.2 discusses thermal analyses conducted on the closure design of the North Country Rock Pile (NCRP) including climate change scenarios for a simulation period of 100 years. Little information is provided within this report, as the design specifications of the cover, test piles and climate change scenarios were all completed in 2013 as part of a PhD thesis by Hoang Pham entitled "*Heat transfer in waste-rock piles constructed in a continuous permafrost region*". It is assumed that no other more recent studies have been conducted. As part of the study, Pham took in situ ground temperature measurements within a waste rock dump at the Diavik Mine in 2010 and 2011. These measurements are more than ten years old. It was also assumed that the mine site overlies continuous permafrost. It is unknown whether current ground temperatures at varying depths, and seasonally, are the same as the temperature measurements taken more than 10 years ago, and whether the site still overlies continuous permafrost. It is also unknown whether the active layer zone depths, seasonally, are the same, and if the permafrost layer is the same thickness.

Golder's 2018 report "*Diavik Diamond Mine North Country Rock Pile Closure Design*", Attachment E: "*TDR Probe Data*" provides seasonal temperature measurements within the till layer between 2019 and 2020. The *"2021 Reclamation Completion Report Waste Rock Storage Area- North Country Rock Pile"*, Appendix H: *"2021 TDR Readings"* also provide one year of seasonal temperature measurements from the till layer. It is not known at which depth these measurements are taken. Further measurements are needed to provide a complete understanding of seasonal temperature changes within and below the NCRP over time.

Recommendation: These measurements (ground temperature at varying depths, and seasons; active layer and permafrost layer thicknesses; continuous permafrost zone confirmation) should be re-taken for the NCRP.

Currently the cover design consists of 3 m coarse run-of-mine rockfill (ROM) overlaying 1.5 m till. Numerical simulations of climate change scenarios predicted that this cover design would result in the 0°C isotherm (active layer) at a depth of 3.9 m to the year 2110. By using coarse ROM rockfill to allow convection through the cover, and ensuring that the till remains saturated, this depth to the 0°C isotherm is predicted to be reduced. These are standard thermal cover design methods as outlined by Stevens et. al., 2018. The climate scenarios case studies for the cover designs were based on climate modeling analyses conducted by Environmental Modeling and Prediction P/L Australia, who conducted these analyses in 2008. Climate modeling scenarios predicted annual mean temperature increase of 0.056°C/yr. This value was used in the case studies/thermal analyses of the cover design. However, warmest temperature scenarios were predicted to be 0.061°C/yr, with the highest increase predicted in January at a mean increase of 0.086°C/yr. These predicted increases were not factored into the climate change scenario case studies for thermal cover design analyses.

Based on the information above, CoreGeo has the following concerns:

- The climate change prediction scenario ranged from 1970 to 2060, which is 37 years from now. The predictions do not go far enough in the future to consider closure and post-closure 100 years from now. In addition, this prediction was completed in 2008. Fifteen year later, there is more information known, and updated, more accurate climate change scenario predictions available. Climate change parameters obtained in the recent Diavik Diamond Mines Climate Change Assessment (Golder, 2021) should be used in the thermal modelling. Also, Pham (2013) used only ten years of site-specific ground temperature measurements to apply the climate change scenario to the thermal cover design case studies, whose numerical simulations modelled 100 years. **Recommendations**: The updated climate change assessment, Diavik Diamond Mines Climate Change Assessment (Golder, 2021), should be applied to thermal modelling cover design analyses. Warmest temperature scenarios (95th percentile) should be applied to thermal cover climate change numerical analyses.

- The case study numerical simulations of the thermal cover design only considered predicted temperature changes over time, and not precipitation projections. Pham (2013) recommended that the till layer in the cover remain at 90% saturation (90% volumetric water content). There was no discussion or analyses completed on the effect of increased precipitation over time due to climate change, and how that could affect the saturation level of the till layer, including the possibility of over-saturation. Additionally, there was no discussion on how increased predicted precipitation, including extreme events such as storm surges and flooding, could affect water management and increased ponding along the sides of the North Country Rock Pile.
  Recommendations: Updated thermal modelling of the NCRP cover should incorporate predicted precipitation changes from the Diavik Diamond Mines Climate Change Assessment (Golder, 2021). These predictions should be applied to the till design layer of the thermal cover, and water management designs of the NCRP.

Finally, Pham provided follow-up recommendations, as there were still gaps in his study of the NCRP thermal cover design, summarized here:

- Test piles were much smaller than the NCRP, and so measurements should be taken from the NCRP, to measure the thermal regime of the bedrock beneath the pile and within:

  - Additional thermistors beneath and within the pile should be installed.
  - Additional heat flux plates should be installed.

Currently, Golder and Rio Tinto took temperature measurements in 2019, 2020 and 2021 within the till. It is unknown at what depths within the till layer these measurements were taken (Golder, 2018; Rio Tinto, 2021).

- Additional numerical simulations are needed to examine the influence of water transport on the thermal behaviour of the cover.

  Recommendation: These additional actions should be completed if they have not been already.

3.6 Diavik Processed Kimberlite Containment Facility: Rockfill Option Closure Design

Section 5.1 of the report discusses thermal modelling of the Processed Kimberlite Containment Facility (PKCF) cover- rockfill option closure design. The following concerns were identified:

- The report does not provide geochemical characterization of the material within the facility, and there is no consideration for how this material will be managed and the facility designed based on geochemical characterization. The 2022 "*Processed Kimberlite Management Plan, Version 7"* describes geochemical characterization work that has previously been conducted with reference to the 2011 "*Interim Closure and Reclamation Plan, Version 3.2*". Section 4.3 of the PK Management Plan explained that geochemical and mineralogical characterization of kimberlites has been completed along with pore water sampling and geochemical analyses, including from shallow thawed zones and ice lenses. Pore water sampling is to continue annually. No information was provided as to how PAG material is stored in the facility. Discussion of monitoring the facility post closure was not included.

  Recommendations: Discussion of the ARD/ML characterization of the materials in the facility should be discussed, along with how this informs the material placement and design of the facility. Monitoring (including groundwater monitoring) planning at closure, including cover performance should be discussed.
- There is no discussion of the active layer and permafrost depths underlying the facility. Ground temperature measurements, and measurements within the Extra Fine Processed Kimberlite (EFPK) were not taken.

  Recommendation: Ground temperature measurements below the facility and within should be measured seasonally, to characterize the extent of permafrost and active layer, as well as temperatures within the facility year-round.
- Cover trials were short-term and only conducted in the spring and summer months. There were no year-round trials conducted.

  Recommendation: Cover trials should be conducted year-round to understand the cover performance year-round.
- Precipitation changes (increases) due to climate change is not considered in the climate change scenarios within the thermal cover modelling.

Recommendations: Thermal cover modelling climate change scenarios should include precipitation changes. This modelling should include moisture transport within the facility. Water management should address potential increases in precipitation due to climate change.

- Climate change scenarios use a temperature increase of 5.6°C over 100 years. This value is likely taken from the 2008 study from Environmental Modelling and Prediction P/L Australia.
  Recommendations: Climate change scenarios for thermal cover modelling should be re-run with up-to-date climate change prediction values. Long-term site-specific data should be incorporated into climate change predictions.
- Thermal modelling was conducted in 1D. Stevens et. al. 2018 recommend 2D modelling to allow for analyses of slopes, geometric effects, boundary conditions modified to meet surface conditions.
  Recommendation: Thermal modelling should be conducted in 2D.

4. CLOSURE

If you require any additional information or clarification, please do not hesitate to contact us.

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